CICE Consortium

Progress Report

January 2020 - February 2021

Overview

The CICE Consortium accomplished a number of major upgrades to our sea ice model code, scripts and testing infrastructure, while strengthening our visibility in the international modeling community. We released CICE versions 6.1.1, 6.1.2, 6.1.3, and 6.1.4, all of which include updated releases of Icepack. Major new capabilities include an implicit solver for viscous-plastic dynamics, diagnostic water isotopes, a new default atmospheric data set for all of our supported grid configurations, a conda environment for easier code porting to other platforms, and more robust and flexible scripts for running and testing the code. In addition, the team held our first user workshop and tutorial in February 2020, and published a peer-reviewed paper highlighting pros and cons of using research codes for operational forecasting.

A list of member institutions, their representatives, and their contributions to the Consortium is provided later in this document. Based on the Sponsors' recommendation, the Institute of Oceanology of Polish Academy of Sciences (IOPAN) was invited and joined the Consortium, sharing responsibility for testing with the Naval Research Laboratory, Stennis Space Center. IOPAN replaces the Naval Postgraduate School as a formal Consortium Member; the Regional Arctic System Model (RASM) is acknowledged for its funding support. Due to funding constraints, NCAR has reduced its level of effort for the Consortium to 0.5 FTE. NCAR has contributed a full FTE to the Consortium since it started, which has been crucial for getting our processes up and running. Following discussions with sponsors at both GFDL and NASA, the Consortium team leadership recommends that NASA join the Consortium and that GFDL step down. NASA engagement brings remote sensing expertise along with related datasets and tools to the Consortium; NASA can co-lead the Community Support team with NSF/NCAR. GFDL's participation is more suitable as a community member rather than an institutional member of the Consortium, and other NOAA divisions continue to participate, particularly OAR, NWS and the ESPC office. Per the Consortium's governance documents, several of these changes require approval of the Executive Oversight Board or the Sponsors group, which will be convened in early 2021. As DOE's new program manager for Earth System Model Development, Dr. Xujing Davis has taken over leadership of the Sponsors group.

The Consortium's primary goal is to accelerate model development for sea ice research and the adoption of those developments into operational codes at forecasting centers. Successes this year include

- DMI is implementing CICE6 into their new operational system
- CICE v6.1 is being implemented in the Navy ESPC model.
- CESM modifications merged back into the Consortium's codes have enabled CESM and the NOAA/UFS system to begin running coupled with CICE v6. NOAA is systematically benchmarking its fully coupled systems including CICE6.
- Bug fixes from CESM have been implemented in E3SM
- Marte Hofsteenge of Wageningen University, The Netherlands, completed her master's thesis entitled "Evaluation of 1D and 3D simulations with CICE: sea ice thermodynamics and dynamics during the SHEBA expedition", as a first step for a similar MOSAiC study

- The FESOM research group at the Alfred Wegener Institute, Germany, has adopted Icepack and published a paper, demonstrating the improvements

A number of projects external to the Consortium have contacted us directly or through the Forum. As a result, Consortium team members are working with them on wave-ice interaction, melt ponds, radiation and discussions regarding porting the MetOffice's coupling scheme for mushy thermodynamics. A new NASA project has been funded to use CICE-DART with ICESat-2 sea ice data assimilation, including NASA and DOE Consortium team members working with University of Washington collaborators. In addition, Consortium team members are participating in MOSAiC projects at NCAR (with U. Washington) and as part of the RASM project.

The CICE Consortium team maintains its vitality and cohesiveness through monthly telecons and other meetings scheduled as needed, and through communications via GitHub tools. In addition to overseeing the Consortium's activities and other modifications to the Consortium's resources and code releases, management tasks included meeting with and updating the Consortium's Sponsors group in February 2020, engaging working groups on special topics, and prioritizing tasks by mapping them onto potential release targets. Careful review and testing of code changes, including formal Quality Control testing, synchronous documentation, and maintaining backward compatibility to the extent possible remain critical for code trust.

Major improvements for Icepack since January 2020 include

- Improvements to the interface between Icepack and host models to be more flexible, robust, backward compatible and generally more user friendly
- Improved internal conservation checking
- Code ports from CESM into CICE v6, especially water isotope diagnostics
- Updates to the floe size distribution capability for wave fracturing and adaptive time stepping, improving performance

CICE model development highlights

- Implicit solver for viscous-plastic (VP) dynamics
- Additional testing and improvements for landfast-ice, including bathymetry data
- Made JRA-55 atmospheric forcing the default for all configurations
- Additions and updates to NUOPC drivers for running CICE in coupled models
- Upgrades for data assimilation using JEDI

Software engineering upgrades

- Developed conda environments for easily porting both CICE and Icepack to other machines such as laptops
- Implemented a new code coverage testing capability for both CICE and Icepack (lcov)
- Enhanced the software environment, such as how libraries are used within the code
- Developed methods to support compilation of CICE into a library
- Improved flexibility of scripts for setup/build/run/submit
- Addressed compiler issues
- Ported the code to numerous machines

Team members strive to maintain the Consortium's visibility in and interactions with the larger community. This year, we held our first-ever User Workshop and Tutorial for CICE and Icepack, described in more detail below. We also encouraged use of the Forum for questions and sharing information by making it more visible in the Consortium's documents and web pages. Following the "Towards defining a cutting-edge future for sea ice modelling" workshop in Iceland, September 2019, Consortium members co-authored and submitted a workshop report to *BAMS*, and follow-on conversations resulted in a peer-reviewed publication in *Current Climate Change Reports* and an opinion piece for *SIAM News*. We also continued to grow our Zenodo community by posting additional resources, including new code releases, data and graphics. Links to all of these resources are provided in tables below.

Home page	https://github.com/CICE-Consortium
Zenodo Community	https://zenodo.org/communities/cice-consortium
Resource Index	https://github.com/CICE-Consortium/About-Us/wiki/Resource-Index
Forum	https://bb.cgd.ucar.edu/cesm/forums/cice-consortium.146/
CICE repository	https://github.com/CICE-Consortium/CICE
CICE releases with lists of enhancements and bug fixes	https://github.com/CICE-Consortium/CICE/releases
Icepack repository	https://github.com/CICE-Consortium/Icepack
Icepack releases	https://github.com/CICE-Consortium/Icepack/releases
Project boards	https://github.com/CICE-Consortium/CICE/projects
Trunk from subversion repository	https://github.com/CICE-Consortium/CICE-svn-trunk
Archived subversion repository (private, requires permission)	https://github.com/E3SM-Climate/CICE-archive

2020 Work Plan

The following text updates the status of each of the items we called out in our 2020 Work Plan.

Tasks completed

Add option for implicit dynamics solver

ECCC has completed this work and merged it into the Consortium's CICE repository. The system of nonlinear equations resulting from the VP discretization is solved using an iterative Picard solver, and the underlying linear systems are solved using a matrix-free Krylov approach.

With both VP and EVP options, there is potential to refactor the code to reduce duplication and better reuse code. Keeping the vectorized (EVP kernel) and nonvectorized dynamical solvers in sync with each other will be a challenge. We can minimize this challenge by moving parts of the 1d routine to the 2d versions.

Add probability based landfast ice grounding scheme

ECCC is developing this new option for the seabed stress based on the probability of contact between the ice (based on the thickness distribution) and the seafloor. The code has been merged into the CICE repository and they have a paper in preparation.

Complete development of the floe size distribution tests

Floe size distribution tests have been updated, and an inconsistent parameter value was fixed.

Complete port of CESM features into CICE v6

CESM's sea ice isotopes and atmospheric boundary layer code modifications were merged into Icepack, along with expansion of the shortwave components available for ocean-ice coupling. These changes were needed for porting CICE v6 into CESM, in preparation for coupling with MOM6.

Mushy thermodynamics

A mushy-layer issue occurs in CESM in regions of very thick and rapidly melting ice in the Canadian Arctic Archipelago, in which thick (>10 m) layers of ice completely melt from within the sea ice column. NCAR developed a work-around that redistributes shortwave radiation in the ice column, which prevents it from concentrating in and melting through thick internal layers.

CICE and Icepack physics bug fixes and software upgrades

In addition to the changes noted above, the order of operations in the albedo calculation was altered for restart consistency, and bugs were fixed for snow melt, aerosols, and initialization of sea ice biogeochemistry. I/O issues addressed in CICE include adding the zenith angle to restart files, reading T grid variables directly, upgrading diagnostic output to be more informative, and adding an option to rotate wind and stress from/to the computational grid (from true north). Some general bugs in the I/O implementation were not causing problems in standard configurations, but were detected with extended I/O testing. Bugs also were fixed for padded decompositions and OpenMP, including threading in the Macros files for some machines. The codes continue to be cleaned up, e.g. removing old vector and other CPP directives.

Completed Pull Requests

From January 2020 through February 2021, the Consortium team submitted, reviewed and merged 138 Pull Requests (PRs) into the CICE and Icepack repositories, about 2.3 per week. 92 PRs were merged for CICE and 46 for Icepack, for the completed tasks above and continuing work below. Many additions and corrections were also made to the About-Us repository and all of the wikis.

Continuing or ongoing tasks

Move to JRA-55 for all reanalysis forced tests

We have generated JRA-55 forcing files to post. How to best serve our testing data is an ongoing discussion, especially now that we are beginning the deprecation process for the older data sets. As we had done for the LYq (Large and Yeager/AOMIP) forcing data, we are preparing instructions and scripts for users to create their own CICE forcing files using the original JRA-55 data, because the JRA-55 files are quite large. We have posted 5 years of JRA-55 forcing files, breaking up the large, tarred data files into smaller, logical groupings and publishing them on Zenodo. The older data that we plan to deprecate will remain available there.

We are currently performing 10-year runs on each of the 3 CICE grids, to test the JRA-55 forcing files and create initial condition files for starting at different times during the year. Sample output from these runs will be posted on our wiki.

Increase code coverage of test suites

Improving code coverage of our tests is an ongoing effort. The 'codecov' software as a service platform did not perform as well as we wanted, so we moved to a different tool, 'lcov', which works well but does not have as flashy a user interface. We are keeping our 'codecov' scripts available in case of future need. This year we have reviewed the test suites, made some individual tests more physically consistent, and added tests to increase code coverage, e.g. for the tripole grid, for parallel I/O, and for the 'zsalinity' prognostic salinity option in both Icepack and CICE. Using the new tool, a spreadsheet has been created with prioritized items assigned to team members.

Redesign or update Icepack interfaces to account for needs of DOE's E3SM, GFDL's SIS

We have made excellent progress in fixing the Icepack interfaces, having decided on a design and begun implementing it as new code comes in. For example, the new isotope implementation in Icepack was made backward compatible using optional arguments. Eventually we may implement this approach for existing arguments as well; this will be an ongoing task.

Icepack interface design	https://docs.google.com/document/d/1zK8vvV3KMQ6O7VBaFdDOr4jm6g3gZn7Z8-sDXdxdN8I/edit#heading=h.hyi7l38u12pu

Improve build system

Updating the build system is also an ongoing task. For instance, this year a file containing a user's preferred options was added, and the setup scripts were generalized to allow setup-only, setup+build, setup+build+run and setup+build+submit workflows. Tracking down and addressing compiler related issues continues as new compilers and other software environment changes are rolled out.

Improve automation of testing, documentation

The Consortium's testing and test reporting scripts have been refined to make them more flexible, efficient, and the results more informative. A particular challenge this year was the change in the Travis-CI business model to no longer allow unlimited free testing in the cloud for open-source repositories. The Consortium transitioned our automated cloud testing to GitHub's native continuous integration offering, Github Actions, instead.

Additional testing tasks were completed, including debugging the box2001 test case, and running our Quality Control tests on multiple machines and multiple compilers to make sure that they all pass, comparing across machines and compilers.

Test reports	https://github.com/CICE-Consortium/Test-Results/wiki

Code and documentation maintenance

Consortium work includes a number of software engineering and maintenance tasks, such as cleaning up the namelist and pre-processing directives, updating machine ports, and improving the documentation, diagnostic output and setup/build/run scripts. In addition to those mentioned elsewhere in this document, we also updated I/O options in the code to use 8-byte integers and updated the MPI implementation.

The Consortium's software documentation on the wikis and zenodo continues to be updated, an ongoing task as new code enters the repositories and as users question existing code. Documentation changes this year include clarifications and fixing errors, along with additional guidance for collaborating with and contributing to the Consortium, citing our resources, and using new resources such as the conda environment. A better way to organize all of the documentation, especially the wikis, was proposed and is gradually being implemented. The Consortium's governing documents have been working well. The one policy addition regards the use of newer Fortran versions that might not be supported across all compilers. We continue to secure DOI numbers for each release and related resources.

Guidelines relating to Fortran standards	https://github.com/CICE-Consortium/About-Us/wiki/Software-Development-Practices#new-fortran-features-and-external-libraries

Redesign the CICE time manager

A major upgrade to the CICE time manager is underway, making it much more flexible and user-friendly. The new approach, in which the user specifies dates and/or time periods rather than inputting the number of time steps to take, alleviates problems with leap years and addresses initialization issues. The time manager for Icepack will be updated similarly once we are satisfied with CICE.

Institute unit tests where it makes sense

Unit tests are being added for the time manager refactoring process. Creating unit tests for other parts of the code (other than Icepack itself, which can be considered a "unit" of CICE) is difficult after the fact. One suggestion is to create tests for each of the coupling caps, which we do not test now.

Incorporate the satellite emulator developed by Navy/DOE

A new diagnostic package, The POLar SysTem Analysis Package (Polestar), which includes a satellite emulator, is being developed through a separate DOE program. Moving it into the CICE Consortium's repositories requires copyright assertion from DOE, a process we are working through now.

Polestar specifications	https://doi.org/10.2172/1762702

Add iceberg grounding interactions for fast ice

The iceberg-grounding landfast-ice scheme has been implemented in a branch of CICE v6, and needs to be brought up to date with the current repository before merging. This is nearly finished.

Add Mohr-Coulomb rheology

A Mohr-Coulomb rheology was coded in CICE but is not converging well, requiring further work.

Port new snow-on-sea-ice model from E3SM

Code ports from E3SM are either underway (snow) or planned (radiation). We expect modifications to the Icepack interfaces and further design suggestions as part of this process.

Implement C-grid option

C-grid development is likely to happen later in NCAR's staged process for coupling with MOM. To prevent software conflicts and repetitive work, a number of tasks needed to be completed before the C-grid dynamical core is implemented, including bringing CICE version 6 fully into CESM. This required porting features from the older, B-grid CICE version currently used in CESM into CICE v6 and implementing the new NUOPC cap for coupling with CESM, both of which have been completed. CICE v6 is now being evaluated in the current version of CESM. E3SM is expected to implement incremental remapping advection for more general unstructured meshes, which will apply for C-grid structured meshes, as part of its upcoming next-generation development thrust. Remaining work involves coding the momentum and constitutive equations for the C-grid, a task that has been done before in other models. The Consortium will reevaluate and possibly update its software directory structure to accommodate both B- and C-grid options.

Create kernels for EAP similar to EVP

The new EVP software kernels developed by DMI were tested and merged into the main CICE repository last year. These kernels vectorize the data structures and rely on threading (OpenMP) for parallelism, allowing the dynamics to be run without MPI communication during the subcycling, alleviating a major bottleneck for computational efficiency. There was an OpenMP issue related to the EVP kernel, however, which has now been fixed. Now that the EVP implementation is working, vectorizing/kernelizing EAP is feasible.

Add variational ridging scheme developed by Navy/DOE, including interactions with the ITD and FSD

The variational ridging scheme is being added to Icepack through a separate DOE program and is not yet ready for prime time with the Consortium.

Community Support

The CICE and Icepack workshop/tutorial

NCAR took the lead on organizing a first-ever CICE and Icepack community workshop and tutorial, held February 3-5, 2020 in Boulder, CO. They secured 400,000 core-hours of high-performance computing support from their facilities (Cheyenne) and funding from NSF to support student and postdoc travel. Both the workshop and the tutorial were full, with 36 in-person participants and 10 more online through our webcast. Team members from all Consortium agencies attended, and participants hailed from 10 US universities plus Poland, Australia, and Norway. NSF provided merit-based support for 13 domestic students/postdocs.

As a result of discussions during the workshop and tutorial, a major community request was to develop a set of observations and metrics (international benchmarking project) for developing and evaluating sea ice models. MOSAiC provides the perfect opportunity for this.

Workshop participants also suggested short-term, topical working groups in the following areas of interest:
snow, spectral emissivity, data assimilation, wave modeling, validating the floe size distribution, C-grid dycore, lake/freshwater ice, iceberg interactions with sea ice, and boundary conditions for regional configurations. Longer-term physics priorities include dependence of rheology on model resolution, validating/improving sea ice hydrology (e.g. brine drainage, stability at the ice-ocean interface for nutrient exchange, double diffusive mechanisms), and snow.

Challenges highlighted during the workshop:

- coordinating, utilizing online tools (including the forum)
- determining extent of support for stand-alone models
- porting from development versions of the models
- tools for model evaluation and benchmarking
- software engineering assistance for model developers outside of the Consortium
- reacting to changing computing platforms

Tutorial participants performed Quality Control tests, comparing CICE standalone and CESM coupled results. Links to all of the presentations and hands-on activities are available from the website. A report to NSF about the tutorial is included here as an Addendum.

About $3500 of student/postdoc funding was left over, which NSF approved to support student travel for teams and working groups collaborating on CICE or Icepack code development tasks. The funds have not been spent because travel was severely curtailed by the pandemic.

While the Consortium would like to provide a workshop and tutorial every year, the level of effort required is more than we currently are able to muster. Instead, we are contemplating holding a user workshop in 2021 (probably online) without a tutorial. The tutorial materials are available online now; the team will discuss how these could be made more helpful for independent study, and we will discuss hosting a fully interactive tutorial for the following year.

General information	https://github.com/CICE-Consortium/About-Us
How to contribute	https://github.com/CICE-Consortium/About-Us/wiki/Contributing
General information wiki	https://github.com/CICE-Consortium/About-Us/wiki
Resource index	https://github.com/CICE-Consortium/About-Us/wiki/Resource-Index
Icepack wiki	https://github.com/CICE-Consortium/Icepack/wiki
Icepack documentation, user guide	https://readthedocs.org/projects/cice-consortium-icepack/

CICE wiki	https://github.com/CICE-Consortium/CICE/wiki
CICE documentation, user guide	https://readthedocs.org/projects/cice-consortium-cice/
Zenodo Community (DOIs)	https://zenodo.org/communities/cice-consortium
Workshop and Tutorial	http://www.cesm.ucar.edu/events/2020/cice-icepack/ http://www.cesm.ucar.edu/events/2020/cice-icepack/coursework.html

Visibility

Our online Forum moved to a new location this year, and with encouragement through links on our online wikis, is seeing increased use. Several Consortium team members monitor and respond to Forum postings. We co-authored a workshop report in *BAMS* and led a peer-reviewed publication for *Current Climate Change Reports*, entitled "Should sea-ice modeling tools designed for climate research be used for short-term forecasting?", including co-authors from across the research and operational communities. Both publications are linked below. A third, online post in *SIAM News* provided a less technical overview of the latter considerations. Additional talks and posters that provided visibility for the Consortium are also linked below.

Lettie Roach, who developed the floe size distribution now incorporated in Icepack, gave a guest seminar for LANL and Consortium members on January 20, 2021, entitled "Waves, winds and floes in the changing Arctic." Consortium team member Bob Grumbine will give a seminar on NOAA metrics March 10.

Elizabeth has been invited to submit an R&D100 entry in 2021 through LANL. Development of the entry materials is underway, and will emphasize our community interface and processes as well as unique aspects of the CICE and Icepack codes and the many different kinds of applications it's used for. The tentative title of the entry is "The CICE Consortium Framework for Sea Ice Modeling."

BAMS	https://doi.org/10.1175/BAMS-D-20-0073.1
Current Climate Change Reports	https://doi.org/10.1007/s40641-020-00162-y
SIAM News	https://sinews.siam.org/Details-Page/the-challenges-and-opportunities-of-one-size-fits-all-sea-ice-models
Workshop and Tutorial	http://www.cesm.ucar.edu/events/2020/cice-icepack/ http://www.cesm.ucar.edu/events/2020/cice-icepack/coursework.html
LANL Computational Physics Student Summer Workshop	Invited seminar, July 29, 2020 (Hunke)
SIAM Conference on Mathematics of Planet Earth	Invited seminar, August 12, 2020 (Hunke)

Georgia State University Physics and Astronomy Colloquium	Invited seminar, October 6, 2020 (Hunke)
CESM Polar Climate Working Group	Contributed talk, Feb 6, 2020 (Hunke)
Arctic Maritime Spill Response Modeling Subgrid-Scale Working Group	Invited talk, June 9 2020 (Roberts)
American Geophysical Union	Contributed talk, December 17, 2020 (Roberts)
Informal MOSAiC Ice Dynamics Workshop	Contributed talk, March 2, 2021 (Roberts)
E3SM poster	https://zenodo.org/record/4122287#.X6sWFy9h1-U
Forum	https://bb.cgd.ucar.edu/cesm/forums/cice-consortium.146/
Zenodo community	https://zenodo.org/communities/cice-consortium
Github government community	https://government.github.com/community/#research

Plans

The Consortium's task list is constantly changing as tasks are completed and new ones arise, many to address issues submitted by external community members. Critical tasks for code releases are organized into project boards. Ongoing, longer term tasks include enhancing the metrics and analysis capabilities available with CICE, continuing to automate the test suites and documentation, deciding if and how data assimilation capabilities that have been developed could be included in the Consortium's repositories, and incorporating other community enhancements as they become available.

Most Consortium activities involve team members from multiple institutions, overseen by the institution responsible for the relevant Consortium Team but often led by people at other institutions. Ongoing and future work in the table below includes some items mentioned above.

Team	Ongoing effort	Lead	Future work	Lead
Testing and Analysis	Complete move to JRA-55 for all reanalysis forced tests	NRL	Create test options with major centers' namelist configurations	NRL
	Increase code coverage of test suites	NOAA IOPAN	include metrics and scripts for verification against (MOSAiC) observations	LANL, NOAA, NASA

	Institute unit tests where it makes sense	NOAA	Incorporate the satellite emulator developed by Navy/DOE	LANL
			Implement MOM6 test domains/cases for CICE	NCAR
CICE dynamical core	Add Mohr-Coulomb rheology	ECCC	Create kernels for EAP similar to EVP	DMI
	Add iceberg grounding interactions for fast ice	DMI	refactor the dynamics code to have unique drivers	ECCC
			Implement C-grid option	NCAR
Icepack	Port new snow-on-sea-ice model from E3SM	LANL IOPAN	Add variational ridging scheme developed by Navy/DOE, including interactions with the ice thickness and floe size distributions	LANL
	Create MOSAiC forcing, benchmarking and evaluation dataset for Icepack in collaboration with the MOSAiC team	LANL, NCAR, NASA	Improve radiation scheme using MOSAiC measurements	LANL
Infrastructure	Redesign or update Icepack interfaces	NOAA	Develop boundary conditions for regional configurations	DMI ECCC
	Improve build system	NOAA	Debug and optimize threading	DMI
	Redesign the CICE time manager	NOAA	Create a user-friendly grid generation tool	NRL
			Design netCDF output for Icepack	NOAA
Community Support	Improve online documentation	NCAR, NASA	Document/publish coupling considerations, including thickness biases	LANL
	Improve processes for documenting how well	NCAR, NASA	Revisit workshop/tutorial needs, plans	NCAR, NASA

	new features have been tested and documented			
General	Address issues and user questions as needed			All
	CICE: https://github.com/CICE-Consortium/CICE/issues			
	Icepack: https://github.com/CICE-Consortium/Icepack/issues			

Challenges

A number of improvements planned for the model this year are closely interrelated, and in some cases, team members' other commitments outside the Consortium have led to delays in their implementation. We generally are able to back-fill with other tasks while waiting for some of these major new additions to be ready.

To reduce code complexity and encourage use of better physical parameterizations, we instituted a deprecation process this year and identified a number of parameterizations and forcing data sets to deprecate. So far, none have been deprecated because users either want to keep the simpler functionality or because we are unsure of the ramifications for other parameterizations of removing a simpler one. For instance, upwind advection is highly diffusive, but it is useful for comparing against other sea ice models that do not offer more advanced advection algorithms. Likewise, the delta-function ice thickness distribution is inaccurate but may still be used for other code simplifications such as one-category configurations. We expect to deprecate some of the forcing code, now that we have implemented JRA-55 forcing, and we continue to look for other ways to simplify the code. The deprecation exercise, even when it's not completed, helps us determine how the community is actually using the code.

The user workshop in February 2020 identified a number of common interests within the community and recommended that the Consortium organize working groups in these areas. We have had smaller groups of developers meet independently of our full-team Consortium meetings to work on topics such as the transition to JRA-55 forcing and changes in the radiation scheme. Encouraging participation in these meetings by the larger sea ice developer community is challenging, and we also have not yet identified the right mechanism for recommended working group topics not on the Consortium's immediate priority list. We began compiling a table of community activities, but this is nearly impossible to maintain for activities beyond the Consortium's institutional membership. In practice, we use our GitHub Issues as a central communication hub and call extra working group meetings as needed; team and community members join the conversation via GitHub Issues and then can be invited for additional meetings.

Our online documentation is excellent but there are still areas needing improvement. For example, we have not found a good way to track and document which software versions we are testing with on all of the various machines -- this information is currently entered manually and updated periodically. Similarly, developers submit PRs with commit messages ranging from highly detailed and informative to nearly empty -- we ask for additional information in PRs, when needed. For new capabilities, it would be helpful to understand how well tested the code is and what the effects of the changes will be. The Consortium continues to discuss approaches for addressing these types of documentation needs, to provide useful information without overly burdening code developers.

The online working environment poses some of the most persistent challenges faced by the Consortium. We use a number of externally developed tools, many of which work well much of the time and make our tasks easier, such as automatic testing of both the code and the documentation. When these tools fail, the reasons can be quite opaque. We have had to move some of our resources or tools, for example the forum moved locations and we changed to a different 'code coverage' tool. These types of challenges are expected in a dynamic, online environment, and the broad experience provided by the Consortium's team members enable us to address them quickly, as they arise.

Finally, an ongoing discussion relates to how far Icepack should be developed as a stand-alone model. For instance, some users have requested that we add I/O infrastructure using netCDF, which would make the column physics model easier to develop, test, and use as a stand-alone tool, but users who want to incorporate Icepack into their host sea ice and earth system models prefer a slim, clean code. For example, some models (e.g. E3SM and DEMSI) have implemented Icepack by only importing the columnphysics subdirectory. This keeps their code more clean, but hampers their ability to share code with the Consortium (in either direction). A similar conversation is underway for CICE with respect to incorporating external software packages that, while they provide useful capabilities, would also need to be installed on everyone's computing systems. In both cases, the additional infrastructure and capabilities would increase the maintenance workload for the Consortium. This will be a central topic of discussion over the next year, particularly as the newest versions of Icepack and CICE are adopted by modeling centers.

Major agency contributions since January 2020

Agency/ Institution	**Sponsor, EOB Member**	**Team members**	**Contributions**
DOE/LANL	Xujing Davis, Renu Joseph Dave Bader	Elizabeth Hunke Andrew Roberts Nicole Jeffery Matt Turner	Project leadership and reporting (prioritization, planning, and oversight); Icepack updates esp. zsalinity, FSD; improved code coverage, documentation, plotting scripts; visibility including authoring publications, code releases, Zenodo curation

NSF/NCAR	Anjuli Bamzai and Eric DeWeaver, Jean-Francois Lamarque	David Bailey Alice DuVivier Marika Holland	Community liaison, workshop/tutorial planning, forum oversight and response, documentation, isotopes, shortwave components, mushy thermo work-around, code release assistance
DoD/NRL	Dan Eleuterio, Ruth Preller (EOB Chair)	Rick Allard David Hebert	Extended test design/ implementation, JRA-55 forcing data
NOAA/OAR/WPO	Arun Chawla	Tony Craig (contractor to NOAA)	Software engineering (SE), esp. Icepack interface, coupling infrastructure, run/build scripts, I/O, scheduled/extended testing, automation, code coverage, NUOPC caps; leads all code releases
NOAA/NWS	Hendrik Tolman	Bob Grumbine Bonnie Brown Mark Olsen Maureen Brooks Jessie Carman	Metrics development, upgrades for JEDI data assimilation; administrative support
NOAA/OAR/GFDL	Ram Ramaswamy	Mike Winton	Icepack interfaces
ECCC	Pierre Pellerin	JF Lemieux Philippe Blain Frederic Dupont	Implicit VP solver; improved landfast ice parameterization, bathymetry data; SE support including conda environments, libraries,

			improved run/build scripts; documentation improvements
DMI	Jacob L. Høyer	Till Rasmussen Mads Ribergaard	EVP kernel, dynamics testing, NUOPC cap, OpenMP threading
IOPAN	Slawomir Sagan	Robert Osinski	Testing in RASM for both forced and fully coupled configurations

Trackable Consortium Output

Products	**Identifiers**
Through June 2018	
CICE repository	http://doi.org/10.5281/zenodo.1205674
CICE v6.0.0.alpha release	http://doi.org/10.5281/zenodo.1205675
Icepack repository	http://doi.org/10.5281/zenodo.1213462
Icepack v1.0.0 release	http://doi.org/10.5281/zenodo.1215746
Icepack v1.0.2 release	http://doi.org/10.5281/zenodo.1213463
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CICE v6.1.0 release	http://doi.org/10.5281/zenodo.3568214
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Icepack v1.1.2 release	http://doi.org/10.5281/zenodo.3516931
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CICE v6.1.3 release	https://doi.org/10.5281/zenodo.4004992
CICE v6.1.4 release	https://doi.org/10.5281/zenodo.4359860
Icepack v1.2.1 release	https://doi.org/10.5281/zenodo.3712299
Icepack v1.2.2 release	https://doi.org/10.5281/zenodo.3888633
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Addendum: Report to NSF for the CICE and Icepack sea ice model tutorial, 4-5 February 2020

Purpose

The CICE Consortium is an international group of sea ice scientists who seek to enhance collaborative sea ice model development for and by the scientific community. The CICE and Icepack models are sophisticated computer code, integrated into many coupled climate system models, that predict how sea ice grows, melts, and moves, and deforms around the Arctic and Southern Oceans. We hosted the first ever CICE tutorial to train participants (1) in the use and development of CICE and Icepack sea ice models both on their own as well as in a coupled model framework, and (2) how to contribute community model developments to the CICE and Icepack models so that the entire sea ice modeling community can benefit from their advances. Training on how to use and contribute to development of CICE and Icepack will enhance understanding of sea ice structure and dynamics and expand the Consortium user and development community.

Tutorial structure

The tutorial took place in Boulder Feb. 4 and 5, 2020. There were 27 tutorial attendees, 13 of whom were early career scientists (graduate students and postdocs) supported by NSF and selected from a merit-based application process. Nine Consortium members attended to present lectures and assist during the hands-on-activities. The tutorial agenda consisted of interspersed short lectures and hands-on activities that followed from themes introduced in the lectures and were designed to enhance understanding of those topics.

Tutorial outcomes

The students practiced running standalone CICE and Icepack and then making code changes to better understand scientific options in the model. They performed statistical testing of their experiments to understand the impact of the code changes and performed quality control testing that is part of Consortium code development procedures. Participants also learned about coupled models in which the CICE or Icepack model are used. Students all ran the hands-on experiments individually, but many worked with a partner or in a small group to discuss their results as they proceeded. The small-group work was particularly effective for participants resolving small snags or discussing the results from the activities. Throughout the hands-on activities, Consortium members were available to help students or discuss results. All students were able to successfully complete the activities and engage in group discussions about their results at the conclusion of each day. The last day, participants completed a “capstone” activity in which they examined and compared the impacts of CICE scientific options in a standalone and coupled framework using the skills they had learned during the tutorial. Information from the tutorial including the agenda, presentations, hands-on-activities, and activity results have been posted online: http://www.cesm.ucar.edu/events/2020/cice-icepack/.

At the conclusion of the tutorial, the participants were sent an anonymous survey to complete and we had a 70% completion rate. Overall the participants felt that the lectures and activities were valuable. The most valuable things they listed from the tutorial included the hands-on activities, basic familiarity with CICE and Icepack, learning different CICE capabilities in different model versions, learning more about the science of coupling CICE, and meeting others working with CICE. Some of the suggestions included having a longer tutorial in order to cover more topics and get more deeply involved in the code and lectures to cover additional topics, and providing a more detailed “cheat sheet” for running CICE.

Participants also appreciated the networking opportunities and would appreciate more opportunities to network within the tutorial setting (there was a big snowstorm during the event, which did force changes in the schedule and made challenging the ability to coordinate after-tutorial events). Most participants said they would recommend a similar tutorial to other early career scientists working with CICE in the future.

Future plans

One goal of this workshop was to encourage international cooperation and contributions among the CICE modeling community, which is inherent in the CICE Consortium's international and cooperative design. A successful workshop will result in: 1) an increase in graduate students and other scientists both within the United States and internationally who use CICE and Icepack within their work; 2) increased community contributions to CICE and Icepack in the next few years that will be included in future model releases; 3) continued contact and future workshops between tutorial participants and CICE and Icepack users. Some of these outcomes cannot yet be assessed (e.g. number of community contributions in coming years), but we plan to keep statistics on these contributions. Each released version of CICE and Icepack have a doi associated with it, allowing us to better assess if there is an increase in users in the United States and Internationally who use the model. We will also keep statistics on the pull requests that result in the coming year or two from tutorial attendees (or their group members). Throughout the tutorial, attendees expressed that they were learning useful skills and making good networking connections.

Several participants inquired into whether there would be future CICE and Icepack tutorials. Based on participant feedback, we believe hosting tutorials every 2-3 years would be beneficial for the community, and that this tutorial size (20-30 attendees) is about the right size for the Consortium members to be able to help the students effectively. In the future it would be preferable to host tutorials in other locations rather than solely at the NCAR Mesa Lab, though a possible concern for this would be the availability of on-site supercomputing resources and support that was essential for the success of the hands-on portions of this tutorial. Being able to fund early career participation was essential for allowing many of the attendees to join this year's tutorial. We were able to fund 13 early career scientists through a merit-based selection process, many of whom expressed that they would have otherwise been unable to attend. Most of the funded early career attendees were from R1 Universities, so in the future we would specifically focus on soliciting attendees from other types of institutions. Additionally, we had requests from more than 10 early career researchers outside the United States for funding that we were unable to provide. Being able to engage international early career scientists and collaborators in a future tutorial would benefit the international cooperation integral to the CICE Consortium's design.

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